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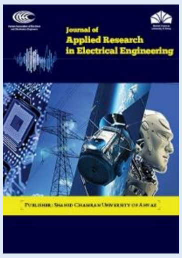

Research Article

Morphological and Statistical Filter-Based Multi-Direction Building Detection for SAR Images

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Abstract: SAR images are used in many applications such as building detection. Extracting the building is very challenging due to the radar nature of the SAR images. However, due to the advantages of radar images such as day and night imaging, building extraction from SAR images is a hot topic. In this context, one of the main challenges is the effect of building orientation on the profile created in the SAR image. Also, the two geometric distortions of shadow and layover affect the SAR image. In most building extraction methods, shadow and double bounce are used as two main parameters in building detection. In this paper, different morphological profiles for detecting shadow index and double-bounce index (DMPSIDI) method have been developed using its combination with the method based on statistical features for building extraction. The DMPSIDI method is a morphological-based method that extracts buildings from SAR images independent of changing their profile. The proposed method is also robust to different data using weighting in the main parameters of shadow and double bounce.

Keywords: SAR, morphology index, building direction, statistical feature

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1. Introduction

Building extraction using satellite imagery is used to generate a spatial map of buildings. Synthetic Aperture Rader (SAR) radar images are very popular today due to the fact that they are capable of capturing in both day and night and can capture in any weather conditions. In the special application of building extraction, high resolution SAR images should be used. There are two categories of methods for extracting buildings from SAR images, which include feature-based and model-based methods. The statistical distribution model of SAR image is used in model-based methods to separate target from background. Markov random field (MRF) is a model-based method [1]. The MRF models can be constructed in Polarimetric SAR (PolSAR) images by using a combination of classical statistical distribution and Wishart mixture model [1]. The feature-based methods extract target by using building features in SAR image. These features are brightness, edge, shadow, and shape that are extracted from primary image. In this article, a feature-based method is used to extract double bounce and shadow area with an edge.

The amount of reflected energy from the scene depends on geometry and land cover in radar images. The scattering can be divided into four types: surface, diffusion, double bounce, and volume scattering [2]. Also, the slope in SAR images usually causes three important geometric distortions including layover, foreshortening, and radar shadows. Radar shadow is due to disability of radar beam in ground surface illumination. Relative to the direction of sending waves, these radar shadows are produced due to the positive inclination of objects which prevents the waves from reaching area behind them. So, shadows are seen with a very dark tone in radar images. Shadow in radar images is an important key to interpret the prominent features. So, this information about the scene such as the height of an object can be obtained through the shadow [3]. Grazing angle and slope are two important parameters in radar shadows that depend on size and intensity [4, 5]. So full shadow will be seen in image if slope of the back surfaces of hills and ridges of the ground are more than the grazing angle because they will not be illuminated by the radar pulse.

A building structure has a double bounce reflection against transmitting microwave signals due to its height and structure [6]. As a result, the building is seen as a bright spot in SAR images. The height of building also creates a shadow effect, and there is a dark area next to bright spots. Therefore, a significant percentage of buildings can be extracted using these two features. Another features of buildings in radar images is their rectangular shape and bright texture appropriate for feature extraction [7]. The morphology profile (MP) method is a way that extracts rectangular and line shapes of building in SAR images [8-10]. The size of building in urban areas is not the same. Also, the aspect angle that is the relationship between building orientation and flight line is different in one region [11]. So, the range of structural elements (SE) must be used [12]. On the other way, a combination of structural and statistical information can be used to accurately extract buildings. In [13], the bright and shadow areas are extracted by using the structural and statistical features of image. Then, the structures are detected separately by combining the results. The statistical properties are extracted using the power ratio (PR) method for shadow areas and the order statistics CFAR (OS-CFAR) method for bright areas. Structural features are also adjusted according to the shape and size of the building; and the Difference Morphological Profiles (DMP) method is used for this purpose. In [14], Using a combination of dictionary learning methods and statistical methods Constant False Alarm Ratio (CFAR) and PR, buildings were detected. On the other hand, one of controversial challenges in facing the distinguishing buildings from radar images is the change in radar cross section compared to the change in geometry [15, 16]. In [17] by using PolSAR images and eigenvalues of the coherency matrix, buildings are detected with different values of brightness level due to change of orientation. Subspace alignment has also been used to robust the method of data modification from different systems or the same as domain adaptation (DA). Sun et al [18] eliminated the effects of changing orientation of building using Geographic Information System (GIS) auxiliary data and used the Fully Convolutional Network (FCN) as a deep learning network. For this purpose, the Compound Gaussian Network (CG-Net) module was introduced, which has the ability to connection to other networks. Cho et al [19] improved effect of changing the shadow and bright area of building in different directions for target detection by fuzzy integration of double-bounce index (DI) and shadow index (SI). The DI index is for detecting bright areas and the SI is for detecting shadows in different sizes and directions.

This paper is an extension of our previous work presented in [20]. Our novelties and advantages in this article are as follow:

- Robustness of the proposed method with respect to changes in the orientation of buildings using fusion of two morphological indicators.
- Detection of buildings with flat and gables roofs.
- Reducing false alarm rate by weighting the indicators in different structural elements.
- Increasing detection ratio by using statistical information of the image

Fundamental of the proposed method are described by explaining Black top-hat (BTH) and White top-hat (WTH) method for DI and SI in section 2. Section 3 represents the data and experimental results. The conclusion and future work are followed in section 4.

2. Proposed Approach for Building Extraction

A useful feature for separating the target from the background in extraction of a building is its structural properties. The building in the image has a specific shape and size range in different urban areas. Due to this feature, a morphological method can be used. The difference morphological profiles for detect shadow index and double-bounce index (DMPSIDI), which is a morphological-based method, is presented in [21]. In this method, two indicators of SI and DI are used to detect shadow areas and double bounce, respectively. DMP is then used instead of MP to consider edge properties. Finally, to make the method more robust to different data, two areas of shadow and double bounce with different weights are considered. In this paper, to increase the accuracy of building detection, the results obtained from Weighted DMPSIDI (WDMPSIDI) are combined with the statistical features of the image and the results are improved. The flowchart of the proposed method is shown in Fig. 1.

2.1. Morphological Method

Spatial features of the image include shape, texture and edge. Using the morphological method, the shape and sometimes the edge can be extracted [22-24]. The determining element in this method is the structural element. The structural element can be linear or nonlinear. In a linear structural element unlike the nonlinear one, direction is important. Due to the rectangular shape of buildings, the structural element should be considered rectangular. There are several methods in morphology. In relation to building extraction, a method must be chosen that takes into account the two parameters of shadow and double bounce. The details of the proposed method are described below.

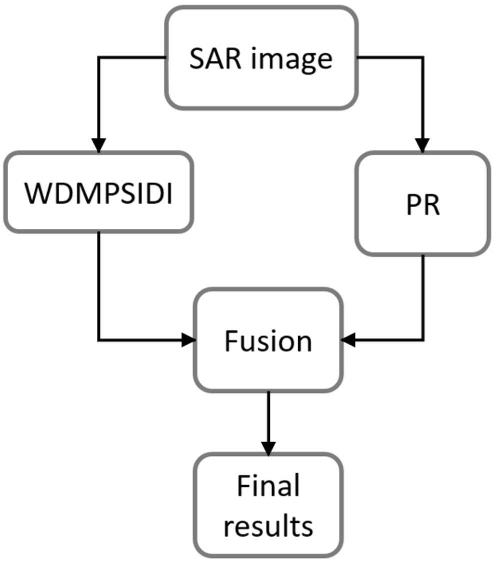


Fig. 1: The flowchart of the proposed method.

2.2. Top-hat Transform

To identify the building in the image, we need features that distinguish the building from the background. These features include double shadows and reflections that are dark and very light in the image and have a rectangular shape. The top-hat converter extracts small elements that are lighter or darker than their neighbours. BTH conversion is used to extract dark areas and WTH conversion is used for light areas [25]. The relationship between these two transformations is as follows:

$$BTH(f) = \phi(f) - f \tag{1}$$

$$WTH(f) = f - \gamma(f) \tag{2}$$

where f is the brightness of the image and γ is the opening operator and ϕ closing is the closing operator.

2.3. WDMPSIDI Method

This method is based on morphology and uses top-hat to extract two parameters of shadow and double bounce in different directions and sizes. Then, by merging the two obtained areas, the location map of the buildings is obtained. The flowchart of the WDMPSIDI method is shown in Fig. 2.

2.4. Double Bounce and Shadow Index

As shown in Fig. 3, the rectangular shape, the bright and shadow areas and the size of the building are the prominent features that distinguish it from the background. The shadow index (SI) is obtained using the BTH conversion and the double bounce index (DI) is obtained using the WTH conversion. *n* is the number of each step and *MP* is the image obtained from the morphology operator.

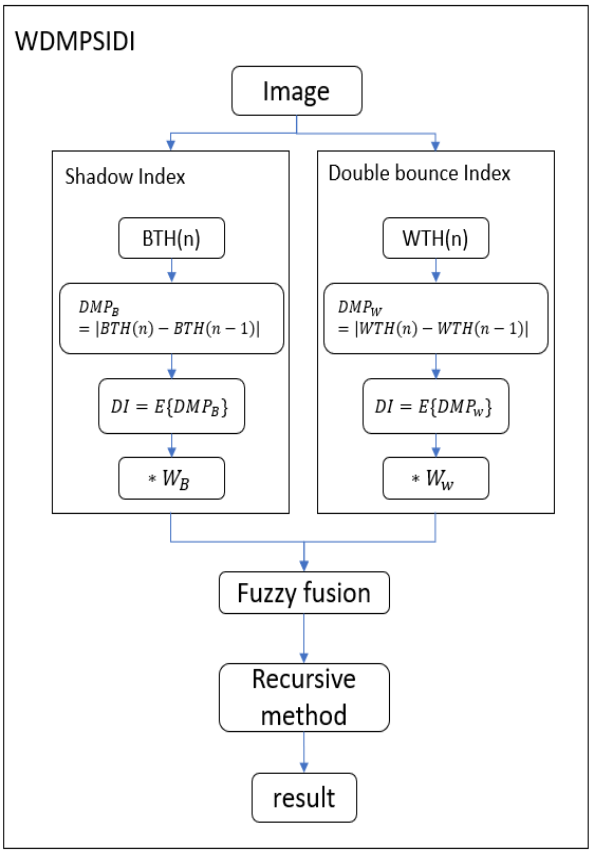


Fig. 2: The flowchart of the WDMPSIDI method.

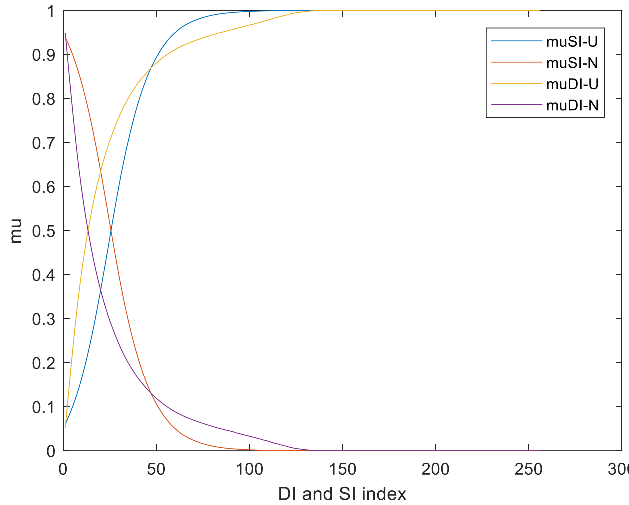


Fig. 3: Membership grade related to the two indicators SI and DI.

To identify different buildings, an image uses a rectangular structural element in different sizes and directions for opening and closing operators. Then, the conversion of BTH and WTH is applied to each, and finally, the two indices SI and DI are obtained by averaging.

$$SI = E\{w_{ij_B}|MP_B(l_i, d_j) - MP_B(l_j, d_{j-1})|\} \tag{3}$$

$$DI = E\left\{w_{ij_w}|MP_w(l_i, d_j) - MP_w(l_j, d_{j-1})|\right\} \tag{4}$$

$$i = 1, \dots, n \qquad j = 2, \dots, m$$

where w_{ij} is a weight for SI and DI in element size l_i and direction of d_j. For the scale parameter l, since buildings have a limited size, the range l_{min} to l_{max} with step Δl is used. Multiscale and multidirectional shadow information is average of DMP.

2.5. Differential Morphological Profile

The DMP method has been used to consider feature of the building edge. In this method, the morphological profile obtained from each stage with the applied structural element is reduced differently from the previous stage. Relationships related to it are as follows:

$$DMP = MP(n) - MP(n-1) \tag{5}$$

2.6. DMPSIDI Method

In this method, MP is obtained for each structural element related to BTH and WTH conversion. Then, to consider the edge property, each MP is subtracted from the MP of the previous step and the DMP of that step is obtained. Finally, by averaging the resulting DMPs, two indicators, DMPSI and DMPDI are obtained.

Now, to determine location of buildings, these two indicators must be combined. Fuzzy integration is used for this purpose. Fuzzy integration for crisp data has three steps. The first step is fuzzification of the morphological index. At this stage, using the cumulative distribution and its complement, the degree of membership of each index is calculated. The membership grade chart obtained in this step is shown in the figure. The second stage is fusion of fuzzy memberships. To do this, the maximum function is used. The third step is defuzzification for decision making. At this stage, binary thresholding is performed.

2.7. Making Robust to Different Data

Depending on the urban area and geometry of the sensor, the number of shadows and brightness in different images is different. For this purpose, two indicators SI and DI with different weights are considered. An iterative loop is also used to estimate the most appropriate parameters required in this method. The loss function is considered in this MSE loop.

$$RMSE = \sqrt{\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[f(x,y)-\hat{f}(x,y)\right]^2} \qquad (6)$$

where $f(x,y)$ is the intensity of pixel in row x and column y, and M and N are numbers of rows and columns of image, respectively. The next challenge in some images is existence of the road, which is recognized as shadow of the building. To eliminate this false alarm, the differential recursive method has been used.

3. Experimental Results

3.1. Used Data

The data was obtained from the Terra SAR-X satellite over Lille Strom, Norway on April 10, 2019 and the capture mode was starting spot light. There are various buildings in the study area. Geographically, it is 59.90 at longitude and 11.04 latitude west. Its polarization is HH and it is obtained in descending orbit. Fig. 4 shows the area under study.

3.2. Results of Implementation

In the first step, the necessary pre-processing approaches have been performed, including the removal of speckle noise and geometric correction of the data. After preparing the data for processing, the proposed method is applied to the data, and then, the appropriate parameters are estimated. The final result is obtained as a binary map. Fig. 5 shows Binary map of the building extracted using three methods. Methods are the proposed, SIDI and PR. In Fig. 6 optical image and GTM is shown.

3.3. Quantitative Evaluation

In most studies of this field, the evaluation of extracted buildings is usually done as an object-based problem. In this paper, a new method for evaluation is presented by using the GTM map prepared pixel-wise where the extracted buildings are evaluated pixel-wise. Table 1 provides a quantitative evaluation of the proposed method and two other methods that are SIDI and PR.

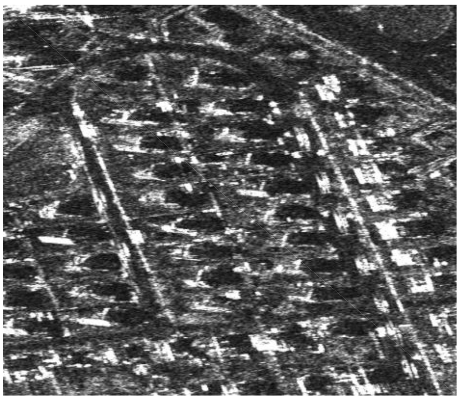
Table 1: Performance evaluation of building extraction.

Approach	FP	FN	TP	recall	precision	F1
Proposed	2920	4877	6148	55.76	67.80	0.6120
SIDI	3795	4196	6829	61.94	64.28	0.6309
PR	36626	1696	9329	84.62	20.30	0.3274

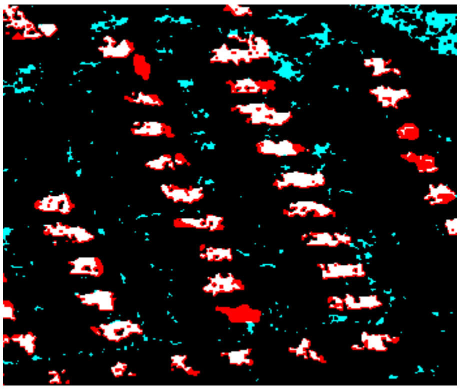
(a)

(b)

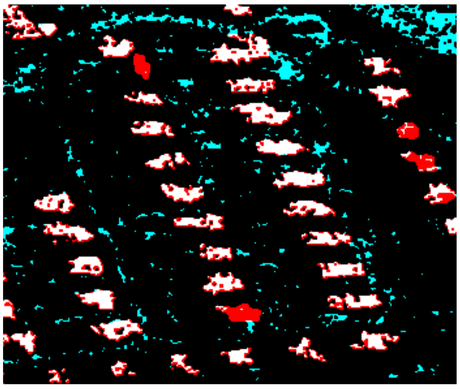
Fig. 4: Area overview, (a) optical image, (b) SAR image.



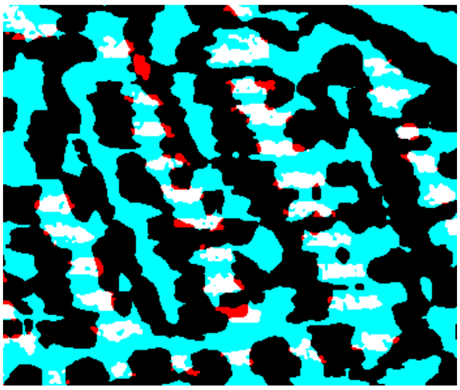
(a)



(b)



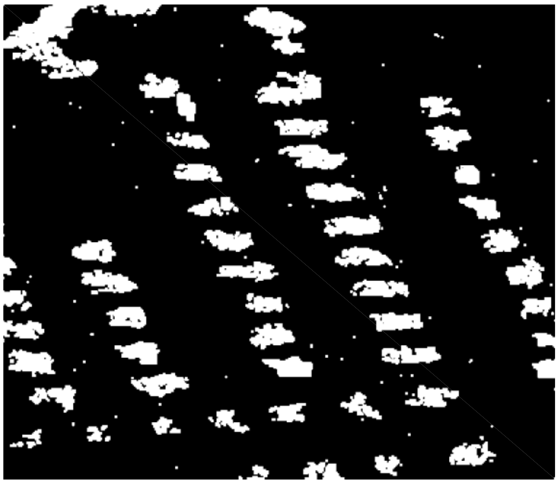
(c)



(d)

Fig. 5: Binary map of the building extracted using three methods, (a) SAR image, (b) false colour of binary map and ground truth of the proposed method and (c) result of the SIDI method, (d) result of the PR method.

(a)



(b)

Fig. 6: (a) google earth image, (b) ground truth.

4. Conclusion and Recommendations

4.1. Conclusion

One of the major challenges in extracting a building is changing its brightness in SAR images. The morphological method is a suitable method to identify the building according to this challenge. Due to the phenomenon of shadow and double reflection, dark and bright areas are created in the image of the building. In the WDMPSIDI method, these regions are extracted using Top-Hat transform and finally merged using fuzzy fusion. To make the method resistant to data changes, two different coefficients w_1 and w_2 for shadow index and double bounce have been used. Another challenge is recognizing roads as false alarms. For this purpose, a recursive method is used in the proposed method. In this paper, by combining the results of WDMPSIDI method and using statistical features, the buildings have been extracted with good accuracy. A basic pixel method is also presented in the quantitative evaluation. This increases the accuracy of the assessment.

4.2. Future Work

One of the suggestions for future work is to develop fuzzy fusion to combine the detection results of shadow and bright areas. Second, location of the building extracted from optical images can be used to increase the accuracy. Also in the evaluation section, a new method can be presented to evaluate the resulting images. The advantages of this method include recognition of tall buildings and high processing speed. However, this method has a lot of false positives in areas with small buildings, and also has low accuracy in certain imaging modes where shadow or bright area has a greater share than the other. To improve this problem, the wavelet transform can be used in future work and the resulting derivatives can be applied as input in this method.

CRediT Authorship Contribution Statement

Fateme Amjadipour: Conceptualization, Methodology, Software, Validation, Visualization, and Writing. **Maryam Imani:** Supervision, Review & Editing. **Hassan Ghassemian:** Investigation & Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy has been completely observed by the authors. This paper is an extension of the authors' previous work presented in 2022 International Conference on Machine Vision and Image Processing (MVIP) [20], which was selected as a top paper to be printed in this journal with some extensions.

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